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Article for AIAA Magazine - Aerospace Engineering

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JET V/STOL TACTICAL AIRCRAFT

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Work on jet V/STOL aircraft started about 15 years ago. In 1947 Ryan received a Navy contract to investigate jet reaction control. This led to the development of a vertical attitude engine test rig which lifted off the ground under its own power in 1950. Later a pilot seat and controls were mounted on top of the test rig and in 1953 this vehicle made the first piloted hovering flight. About this time Ryan received an Air Force contract for the construction of the X-13 airplane (fig. 1). The aircraft was powered by a Rolls-Royce Avon engine of about 10,000 pounds thrust. First hovering flights were conducted in 1956 and complete transition, including the use of the nose hook for take-off and landing were demonstrated in 1957. The original design objectives set for the aircraft were achieved; however, the ground support equipment required and the unusual pilot attitude were disadvantages and this approach was dropped as attention shifted to the horizontal attitude type.

The Bell X-14 vectored-thrust engine configuration (fig. 1) was the first horizontal attitude jet V/STOL aircraft. It is a relatively low wing loading research aircraft and first flew in 1957 using two British Armstrong-Siddley Viper engines. In 1960 the aircraft was repowered with J-85's and variable stability equipment was added to increase its capability as a research vehicle. This aircraft is still being used for flying qualities investigations and related work at the NASA Ames Research Center. Work on the Bell D-188a configuration which was to be an operational aircraft was started under Navy contract in 1958. It was to be powered by eight J-85 engines, two in each tilting tip pod, two in the forward fuselage and two in the aft fuselage. A considerable amount of engineering work was put into the project but it did not proceed beyond the mock-up stage and was terminated about four years ago.

British work on jet V/STOL aircraft started with the Rolls-Royce flying "bedstead" which flew in 1954. This was essentially a hovering control development vehicle and consisted of two Rolls-Royce Nene engines mounted in a metal frame. At about the same time Rolls-Royce started development of special light-weight lift engines. The Short Brothers SC-1 (fig. 1) is a research vehicle powered by five of these engines (RB-108's), and is a development vehicle for both the engines and the special automatic stability equipment the British ~~at an early stage~~ then thought necessary for VTOL operations. The aircraft first hovered in 1957; however, transition was not completed until 1960.

The next and most recent British V/STOL configuration is the Hawker P-1127 vectored-thrust configuration which first flew in 1960. It is powered by a single Bristol-Siddley BS-53 engine which is a high by-pass ratio turbofan configuration especially fitted with four exhaust nozzles that can be rotated to direct the exhaust either vertically downward for take-off and landing or rearward for conventional flight. The efflux from the front fan is ducted to the two forward nozzles and the hot gas exhausted from the two rear nozzles. The primary work that Bristol-Siddley have done on this engine has made this general arrangement the one that is usually brought to mind when the vectored-thrust engine principle is mentioned. It is by no means, however, the only possible configuration for a vectored-thrust engine. The Bell X-14, for instance, can also be classed as a vectored-thrust configuration.

The development of the P-1127, of course, profited considerably from experience obtained on the Bell X-14 and the Short SC-1. The P-1127 has a limited tactical capability and in a Joint U. S. - West German - English program an operational evaluation squadron of nine aircraft is being formed to gain practical experience with jet V/STOL aircraft. The British are reportedly starting the development of a successor to the P-1127, the Hawker P-1154, which is expected to replace the RAF Hunters in Squadron Service.

The French have provided the most recent entry in the jet V/STOL "sweep stakes" in the form of the Dassault-Balzac configuration (fig. 1) which first began hovering trials in the fall of 1962. The Balzac is powered by eight RB-108 lift engines and is essentially a full size (but lightweight) flying mock-up of the Mirage III V lift-engine configuration that the French are planning to develop as an operational fighter.
A more complete history of V/STOL aircraft development is given in ref. 1.

All these aircraft have had very good flight characteristics in several respects. They have been insensitive to wind velocity and wind gusts in hovering, the X-14 exhibiting more effect than theother aircraft because of its light wing loading. Also they have suffered little from ground reflection disturbances at low altitude such as experienced by the Vertol VZ-2 tilt wing and Doak VZ-4 tilt-duct configurations, because of the central jet location in the jet configurations. However, they have all exhibited "suckdown" effects in ground proximity.

All jet VTOL aircraft, except the X-13, are controlled by compressor bleed air ducted to control jets at the nose and tail of the fuselage to provide pitch and yaw control and at the wing tips to provide roll control.

Flight test results have shown that it is possible to provide reasonably good handling qualities in hovering without resorting to stability augmentation, provided that a design effort is made to give them near optimum control power. In the case of the X-14, although good control characteristics were obtained with the control power available with added damping, the control power was never actually optimized for the no-damping case because the higher control power required was not available. In the case of the P-1127, advantage was taken of experience in this country with ~~the~~ a variable stability and control helicopter and with the X-14, ~~variable stability and control aircraft~~. The control about the roll axis, particularly, and the pitch axis have been essentially optimized and the control characteristics have proved to be very good about these axes without augmentation.

Even where control power is optimized augmentation is certainly a desirable aid for performing such missions as ~~the~~ an instrument approach, or for flight at low speed in low visibility. However, augmentation need not be necessary for successful flight in case of emergency. What does this mean to the aircraft designer and operator? It means that augmentation systems can be designed with single channels having limited authority so that, if there is a failure, reversion to manual control will result in successful completion of the mission or diversion to an alternate where weather conditions are satisfactory for visual landing, for instance. Also experience has indicated that rate augmentation, as contrasted with combination rate and attitude or pure attitude systems, are adequate for visual hovering or maneuvering flight where controlling is always necessary to some extent. The attitude types of augmentation complicate pilot control techniques and are unnatural and undesirable for such operation. For operation solely by instruments the attitude system has merit because of long term "hands-off" capability.

The development work to date and the innumerable design studies that have accompanied it (refs. 1 to 5) have led to two general competing concepts,, the composite configuration featuring lift engines and a separate cruise engine as exemplified by the Mirage ~~IV~~ III V, on the ~~other~~ one hand, and the vectored-thrust type configuration, an example of which is the Hawker P-1154 type (fig. 2) on the other. There have been many claims and counterclaims and some heated arguments with respect to these two approaches. At the risk of over-simplifying the problem, the arguments appear to boil down to two central issues, complexity and safety, on the ~~other~~ one hand, and the cruise economy or engine-match problem on the other. There are, in addition, considerations with regard to operational flexibility, the designer's freedom in configuration layout and problems of ground erosion.

There are many facets to the arguments with regard to safety and complexity. In the event of engine failure with the vectored-thrust type configuration during vertical take-off or landing the pilot must eject because engine failure will mean loss of both thrust and control. How much more dangerous this is than conventional aircraft is difficult to assess. On take-off, at least the acceleration and rate of climb of the vectored-thrust engine aircraft are greater than for conventional aircraft so that the pilot may be subjected to the dangerous conditions of low altitude and speed for a shorter period of time than conventional aircraft.

With the lift-engine approach using, say eight engines, there are at first glance eight times as many chances of engine failure. The inherent simplicity of the engine may reduce this by perhaps half, if the short life psychology does not make engine failure more likely. The actual probability of engine failure cannot be established. Offsetting this is the fact that only one-eighth of the thrust is lost and the other engines can be brought up to an emergency rating to at least partly compensate. This is in turn offset by the fact that the failure of an engine creates a large out-of-trim moment. To keep this moment within the capabilities of the control system would require grouping the engines at the airplane's center of gravity which eliminates one of the advantages of the lift-engine approach, namely lay-out flexibility. The only alternative is to shut down an opposite engine. This requires the use of automatic equipment because the lift engines drop to half thrust in about one-tenth of a second; much too fast for the pilot to manually identify and shut down the appropriate engine. This automatic equipment adds another piece of complexity to the airplane and the one that is in the position to cause serious trouble itself if it should fail. Shutting down an opposite engine also results in a 25-percent loss in thrust (two engines out of eight) much too great for the emergency rating of the engine to compensate. The lift-engine configuration is therefore subject to a speed range (0 to about 100 knots) where engine failure may be as serious as in the vectored-thrust approach. Above about 100 knots the wing contribution to lift is sufficient to compensate for a lift-engine failure.

From the pilot's point of view the minimum increase of complexity is achieved with the vectored-thrust engine concept. The pilot has only one additional control, a lever or button to control nozzle position. The nozzles can be ~~located~~ rotated at rates as high as 90° per second and stopped at any angle and reversed at will.

On the lift-engine approach the pilot has eight additional engines to start, check out and control. Also, he has to open and close the inlets and exits of the lift engines. Most of this can be made automatic so that the pilot's job is not greatly increased over a conventional jet aircraft but this automatic equipment creates an added maintenance and logistic problem.

The lift engines have an advantage with regard to configuration layout because they can be disposed symmetrically about the center of gravity (assuming automatic equipment can be used to maintain trim in the event of engine failure) or otherwise can be arranged so as to provide for a convenient weapon bay as, for instance, would be possible between the lift engines and under the cruise-engine inlet duct in the lift-engine configuration shown in figure 2. When a single vectored-thrust engine such as the BS-53 is used, this engine must be placed at the airplane's center of gravity; right where the disposable loads such as weapons should normally be placed. This makes it necessary to carry weapon loads externally or in a bomb bay behind the engine which seriously limits the weight that can be so carried.

Both the engines schemes created problem with regard to cruise configuration aerodynamics if supersonic performance is required. The wave drag of an airplane depends upon its volume and the overall fineness ratio. Both engine approaches add volume as compared to the non-VTOL counterpart. With the lift-engine approach this volume can be distributed so that a more optimum area distribution and fineness ratio can be achieved and the penalty is primarily in increased volume. The vectored-thrust engine approach adds less volume to the aircraft; however, the designer using the type of engine indicated in figure 2 must work very hard to achieve a reasonable fineness ratio and area distribution because of the large diameter of the fan and the forward location of this maximum diameter.

While the Bristol-Siddley people are to be commended for their pioneering work in the vectored-thrust engine principle theirs is not the only possible layout for a vectored-thrust engine. Work is needed on other configurations designed to minimize the problems of weapon stowage and compatibility with aerodynamic requirements.

With respect to the ground erosion and hot gas reingestion problems the vectored-thrust engine approach appears to have a distinct advantage. With this type the nozzles can be turned to the horizontal so the exhaust from the engine is directed aft in the conventional manner during starting, warm-up and checkout operations and need be turned to the vertical for only a very short period of time for take-off. Likewise on landing the nozzles can be immediately rotated to the horizontal and the aircraft taxied away from the point of landing.

The performance that can be achieved with either approach depends upon the designers ingenuity in selecting the proper design compromises, particularly, with regard to cruise aerodynamics and exhaust losses in take-off. There have been many design studies showing one or the other approach superior for the particular mission or missions studied. Out of all this claim and counterclaim it is hard to draw any unanimity of opinion, however, a few points are becoming clear.

Using the pure lift-engine approach, (that is, not deflecting the lift-engine thrust to the vertical) results in the combined weight of the lift and cruise engines being somewhat greater than the weight of the engine in the vectored-thrust counterpart. Also, some installation items such as the inlet louvers and the exit doors for the lift engines add weight to the lift-engine configuration with the result that the fuel available in the lift-engine aircraft is less than that in the vectored-thrust engine aircraft (fig. 3).

In spite of this, the lift-engine aircraft has a greater radius for a M=.9 ~~and a Mach number .9~~ "on-the-deck" mission (fig. 3). This occurs because the cruise engine is more closely matched to this cruise condition. The vectored-thrust engine must be sized for take-off and in the cruise condition is operating in an extremely throttled condition (fig. 4). If a conventional fan engine is used as a vectored-thrust engine it would be operating at about 15 percent of its normal rated power and the fuel consumption would be almost double that of the lift-engine configuration. Vectored-thrust engines will normally need to use a take-off boost such as plenum chamber burning to add energy to the fan exhaust and thereby boost the take-off thrust substantially. This makes it possible to reduce the basic gas generator size and thereby reduce the mismatch. Other improvements, such as variable geometry to vary the by-pass ratio so as to increase the fan thrust at the cruising point, thereby increas~~es~~ing the propulsive efficiency, are possible and need to be investigated.

~~If a Mach number 1.2~~ In a M=1.2 "on-the-deck" mission the vectored-thrust engine configuration shows a greater radius than the lift-engine configuration because at this Mach number the thrust required is higher and the vectored-thrust engine is somewhat better matched thus taking advantage of the extra fuel that it can carry.

The over-size of the vectored-thrust engine even for a subsonic airplane is not all disadvantage. The excess thrust gives the aircraft phenomenal acceleration and rate-of-climb capabilities. Also, the large mass flow of the engine means that in the throttled condition the aircraft will decelerate quite rapidly. These factors combined with the ability to vector the nozzles at will gives exceptional maneuverability and in a reconnaissance or close support missions should enable the aircraft to come in fast, slow down rapidly to flight speed below normal aircraft speeds to take a look or hit otherwise in~~exc~~accessible targets and rapidly reaccelerate out of the danger area.

The work that has been done to date indicates that operational jet V/STOL aircraft that can do a useful job can be built. The question is are they good enough and what remains to be done?

As in all aircraft the range and payload requirements determine the size of the aircraft but does the jet V/STOL aircraft have to have the same range as its conventional take-off counterpart (fig. 5). The ability to use small sites results in a much larger number of operational bases being available and makes it possible to base the aircraft further forward. Conversely if a very long radius requirement results in a large, heavy, and complex aircraft which requires extensive base facilities anyway, the tactical air strip becomes only a small addition to these base facilities and the justification for VTOL is lost. A VTOL capabilitie~~s~~ appears most compatible with shorter range missions and austere site conditions.

How often is true VTOL capability required? STOL operation can increase the mission radius significantly (fig. 6). For take-off distances of the order of 500 feet almost all the increase in radius is due to the reduction in thrust losses, primarily those associated with hot gas reingestion. By using a short ground run the airplane can accelerate out of and stay ahead of the hot gas cloud that it generates. The increase in thrust thus obtained makes it possible to carry more fuel and thus obtain a greater radius. Very little help is obtained from aerodynamic lift at these distances because of the low speeds involved (30 to 40 knots). Aerodynamic lift only becomes significant andproduces significant increases in radius at speeds of the order of 80 knots or so. For take-off distances of 1000 feet and above the increases in radius achieved depend upon the wing configuration used. A variable-sweep wing with full span flaps, in particular, can give very large increases in radii if take-off distances of the order of 1500 feet can be allowed.

But how much does this STOL operation restrict the choice of sites? Only experience with VTOL and STOL operations can give conclusive answers. In order to obtain operational experience that will be meaningful in evaluating relative merits of VTO versus STO it would appear desirable to design for a dual specification, say a STOL radius ~~(with a 2000 feet take-off distance over 50 foot obstacle)~~ about twice that for the true vertical take-off.

Operational experience is also needed in a number of other areas. How much fuel is required for take-off and landing and ~~in~~ is additional hover time required? Jet V/STOL aircraft in the 30,000-pound class burn fuel at the rate of about 700 to 800 pounds ~~of fuel~~ per minute. Operational techniques for minimizing high-powered low-speed flight must be devised. Along with this comes the problem of instrument approaches to a V/STOL base. If a landing is to be made in quarter-mile visibility the approach must be made at about 65 knots in order to be able to bring the airplane to a stop within the quarter mile at about 0.15 g deceleration when the pilot breaks out visually at his intended landing site. This implies that an approach at nearly full power for several minutes and a very high fuel usage. Techniques for minimizing the amount of fuel used in IFR approaches must be developed.

The questions of ground erosion and site preparation cannot be answered conclusively without operational experience.

The foregoing is not intended as casting aspersions at the many analyses and studies that have been made of these operational problems. These studies have provided much needed information and insight. The point is, however, that little additional light can be shed on these problems without operational experience.

Traveling hand and glove with the gathering of operational experience must be the development of the propulsive systems. For lift-engine configuration, in addition to reducing the weight and volume of the lift engines themselves a large effort must be made to solve the airplane complexity problems inherent in the concept. The vectored-thrust engines also, need to be reduced in weight and alternate engine configurations should be investigated. The primary problem, however, is to develop ways for reducing the fuel consumption in the part power cruise mode.

The present situation with regard to lift engines versus vectored-thrust engines for jet VTOL is similar in many ways to the liquid-cooled versus air-cooled engine controversy of the 1930's. It is much to early in the development of either of these concepts to arrive at a choice of one over the other.

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FIGURE TITLES

Figure 1.- Jet V/STOL aircraft that have reached flight test status:

(a) Short SC-1 lift engine research airplane.
(b) Dassault Balzac lift engine airplane - a development vehicle for the Mirage III V.
(c) Bell X-14 vectored-thrust variable stability research airplane.
(d) Ryan X-13 "Wire Hanger" configuration.
(e) Hawker P 1127 vectored-thrust operational evaluation airplane.

Figure 2.- Development work to date has lead to two competing configuration types. The vectored-thrust type as exemplified by the proposed Hawker P 1154 and the lift engine type as exemplified by the proposed Dassault Mirage III V.

Figure 3.- Although the lift engine type can carry less fuel, it has a better radius in a subsonic "on the deck" mission because of the better engine match. Supersonically "on the deck" the vectored thrust type has the greater radius because the engine mismatch is reduced and it carries more fuel.

Figure 4.- The vectored-thrust engine mismatch problem can be reduced by using a take-off boost such as plenum chamber burning and variable-geometry features to increase the thrust of the fan section and decrease the hot section thrust during part power operation.

Figure 5.- The reduced radius capability of the VTOL aircraft as compared with its conventional counterpart is offset by its greater choice of operating bases which makes it possible to base the VTOL aircraft further forward.

Figure 6.- A running take-off allows more fuel to be carried thereby increasing the operational radius. A variable-sweep wing in particular can produce significant increases in radius.

Photographs in figure 1 obtained from the following:

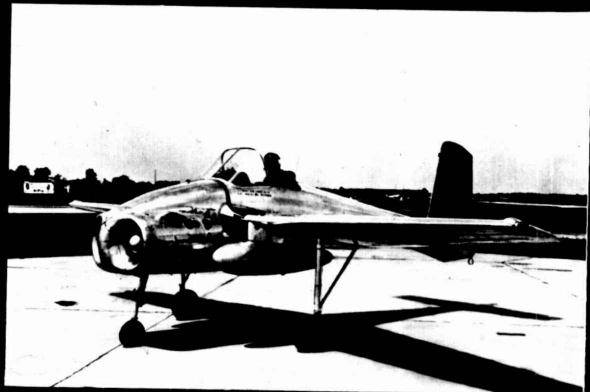
(a) Short Brothers and Harland, Ltd.

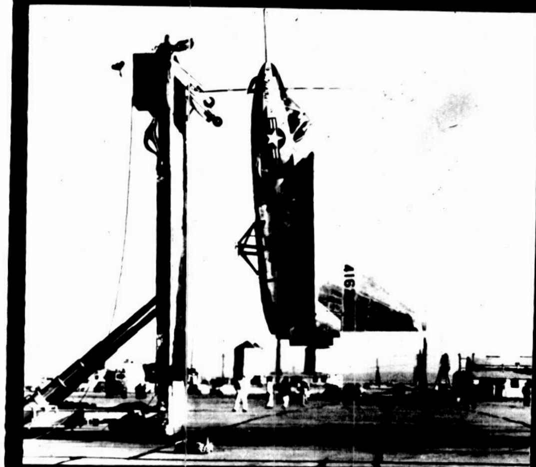
(b) Taken from Aviation Week (December 1962). No contract with Aviation Week has been made with regard to use of this photograph.

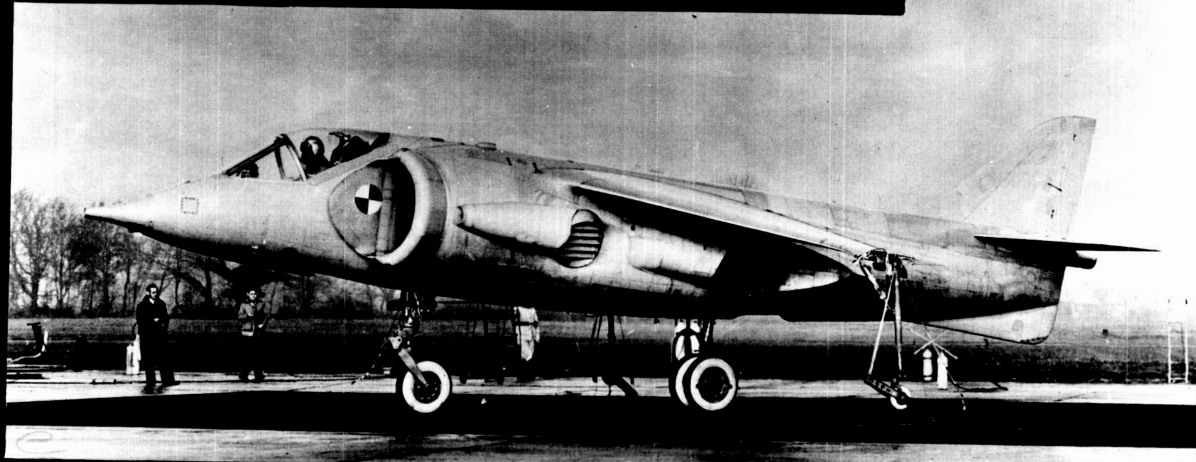
(c) Bell Aerosystems Company

(d) U. S. Air Force

(e) Hawker Aircraft Ltd.







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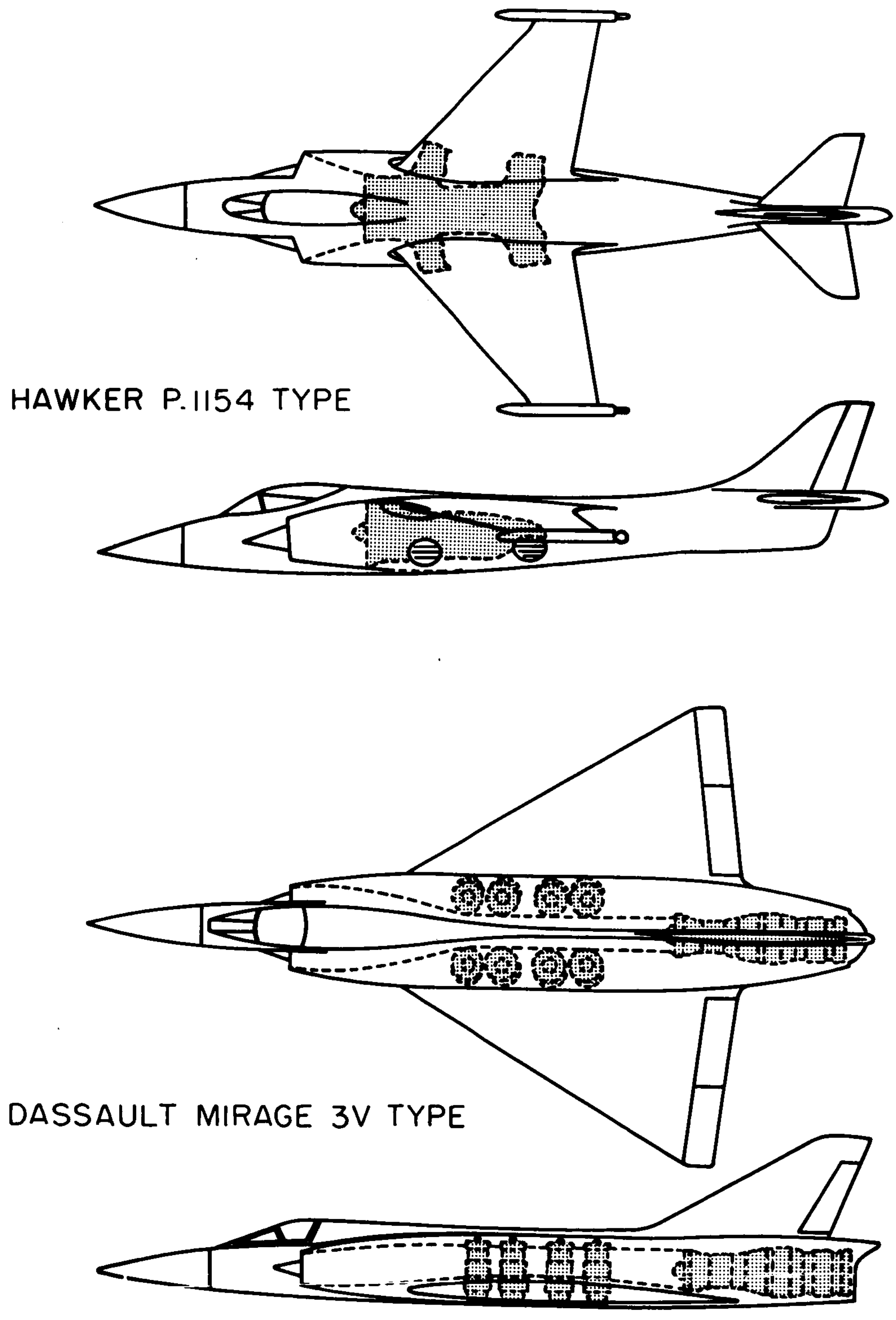

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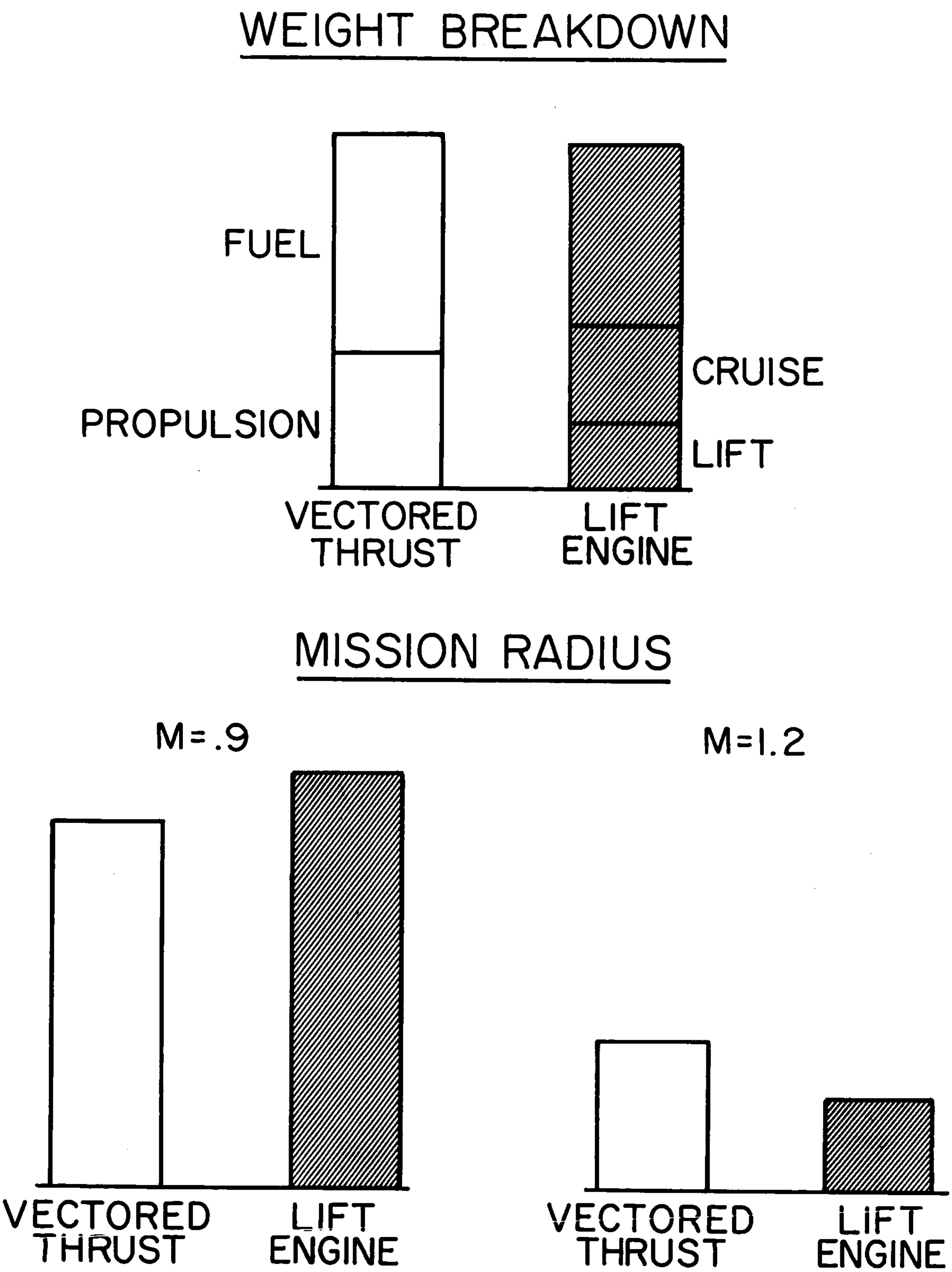

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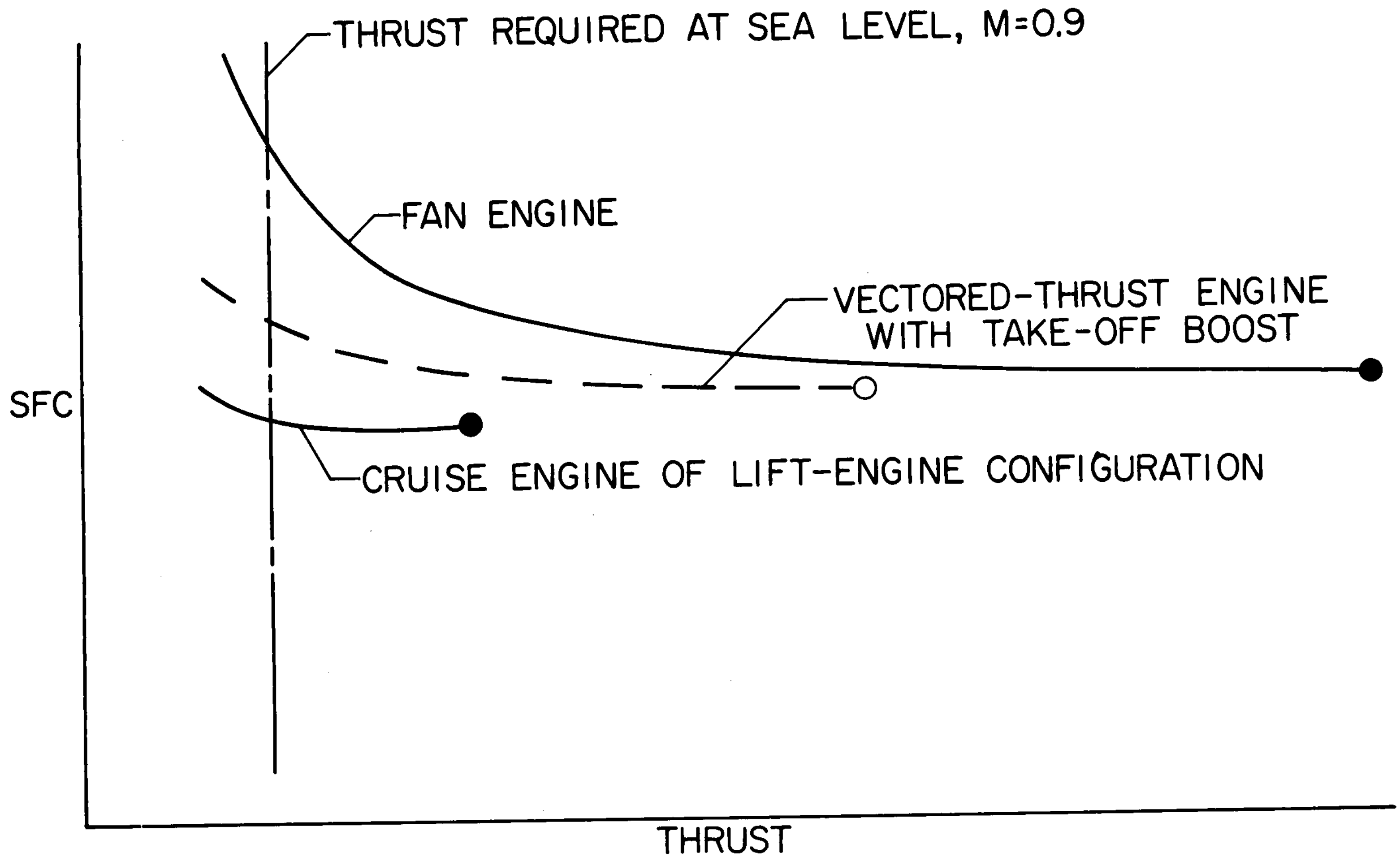

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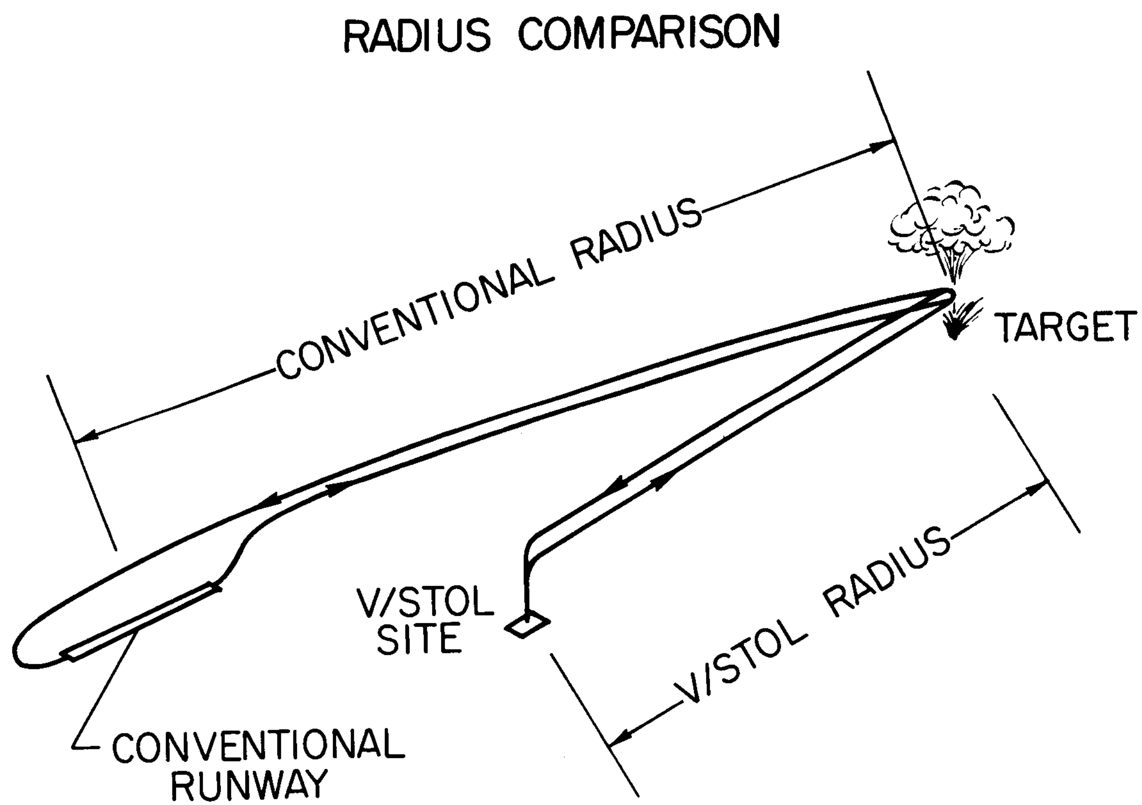

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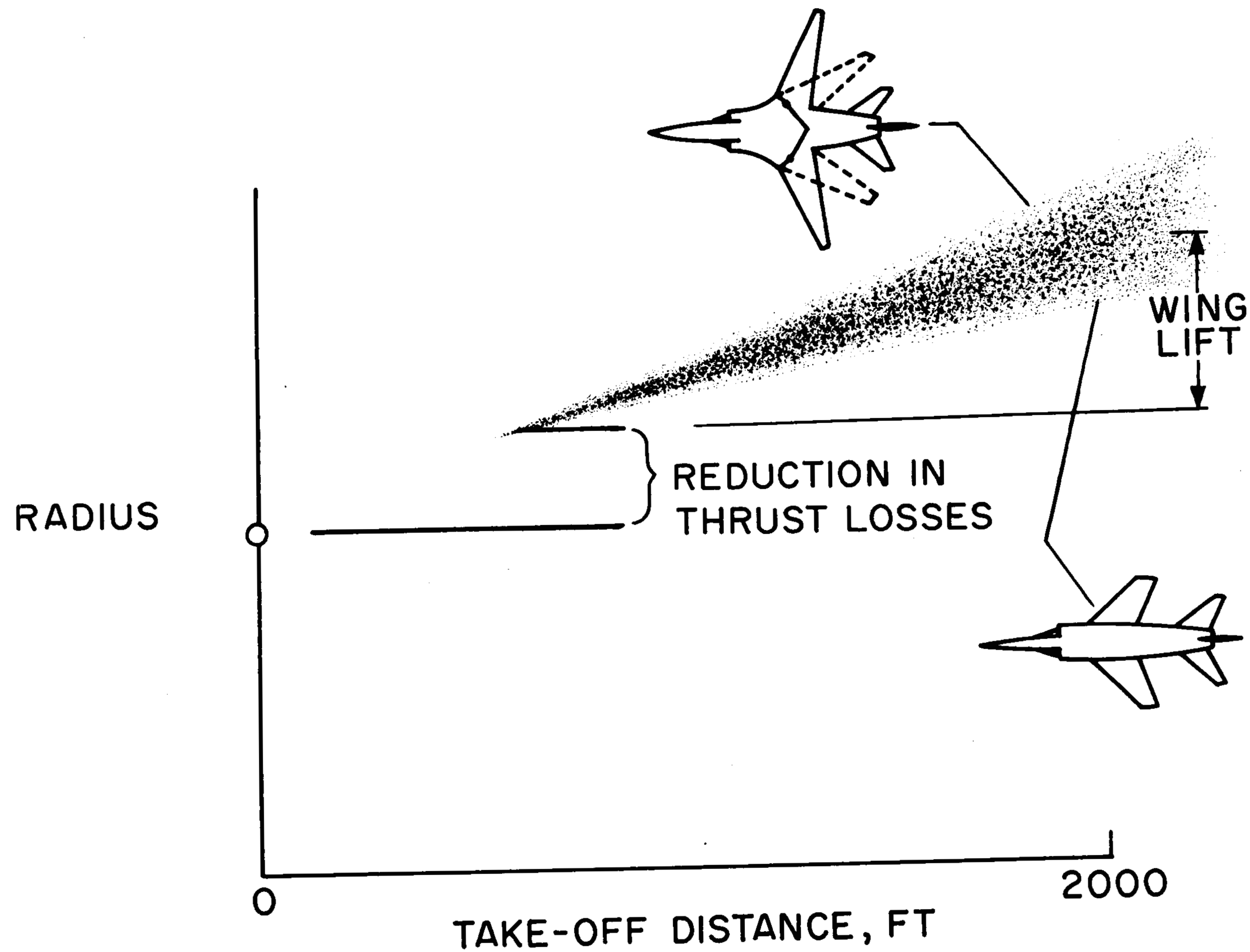

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